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KØBENHAVN
C. A. REITZEL, BOGHANDEL
BIANCO LUNOS BOGTRYKKERI
1925

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ON THE INFLUENCE OF THE CURRENTS UPON THE FREQUENCY OF THE MACKEREL IN THE KATTEGAT AND ADJACENT PARTS OF THE SKAGERAK

BY

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KØBENHAVN
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BIANCO LUNOS BOGTRYKKERI
1925

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I. Introductory remarks.

The influence of the currents upon the occurrence of fishes in a certain area is partly of a direct and partly of an indirect nature. The currents transport the fishes in certain stages of their life, and they influence the temperature, the salinity, the contents of oxygen etc., of the water, and affect hereby indirectly the migrations. Very often it is difficult to see whether the occurrence of a fish species in a certain area on the whole is affected by the currents. In the present paper we shall try to throw light upon this question in case of the occurrence of the mackerel in the Kattegat.

II. The Great Inflow in the Kattegat in the Spring of 1923.

The main features of the current-system in the Kattegat and Belt Sea are well known. In these waters two layers occur usually: a surface layer with relatively low salinity, and a lower layer with relatively high salinity. This stratification is due in the main to the outflow of relatively fresh water from the Baltic and the inflow of relatively salt water from the Skagerak. In the upper layer, till a depth of about 10—25 meters, the resulting current is outgoing, i. e. the water moves towards the Skagerak and the North Sea. In the lower layer the resulting movement is directed towards the Baltic.

The main part of the salt water coming from the Skagerak to the Kattegat becomes mixed with the surface layer, and streams out again to the Skagerak. Only a relatively small part of the salt water in the under current in the northern Kattegat reaches the Belt Sea and the Baltic.

On a cruise with the "Dana" in the Kattegat and Belt Sea in April and May of 1923 we observed an exceptionally high salinity in the lower layer of these waters, and the same was noticed at some stations in the western part of the true Baltic.

It appears from Fig. 1, Section I, that the bottom layer of the eastern and northern Kattegat at the end of April 1923 showed a salinity between 34.78 and 34.97 ‰, which is about 1 to 2 ‰ higher than normally. From Section II it will be seen that the bottom waters in the south eastern Kattegat in the middle of April reached a salinity of 34.88 to 34.94 ‰, or about 3—4 ‰ above the normal. Section III shows the following values observed in the bottom layer of the western Baltic on the 20—21 of April 1923, compared with the normal values:

S. W. of Langeland	30 m	25.46 ‰	Normal value	ca.	22 ‰
S. E. of Langeland	23 -	27.74 -	—	— -	21 -
N. of Fehmern	28 -	25.35 -	—	— -	21 -
E. of Fehmern	22 -	22.50 -	—	— -	19 -
Kadetrende	25 -	20.55 -	—	— -	16 -
S. of Möen	21 -	18.82 -	—	— -	13 -

In connection with the high salinity observed in the lower layer of the Kattegat and the Belt Sea we noticed that the pelagic fauna in these waters was of a more oceanic nature than is usually the case. Various species of *Siphonophora*, which had never before been observed in the Kattegat or Belt Sea, were

found there. According to kind information from Dr. KRAMP two of these species, viz. *Physophora hydrostatica* Forsk. and *Galeolaria truncata* Sars, belong to the warm Atlantic water, while two other species found have a northern distribution.[1] Species of the order *Euphausiacea*, which do not usually go farther into the Baltic waters than the Kattegat, were taken in the Belt Sea, and one specimen of the Genus *Rhoda* was actually taken in the true Baltic east of Falster.

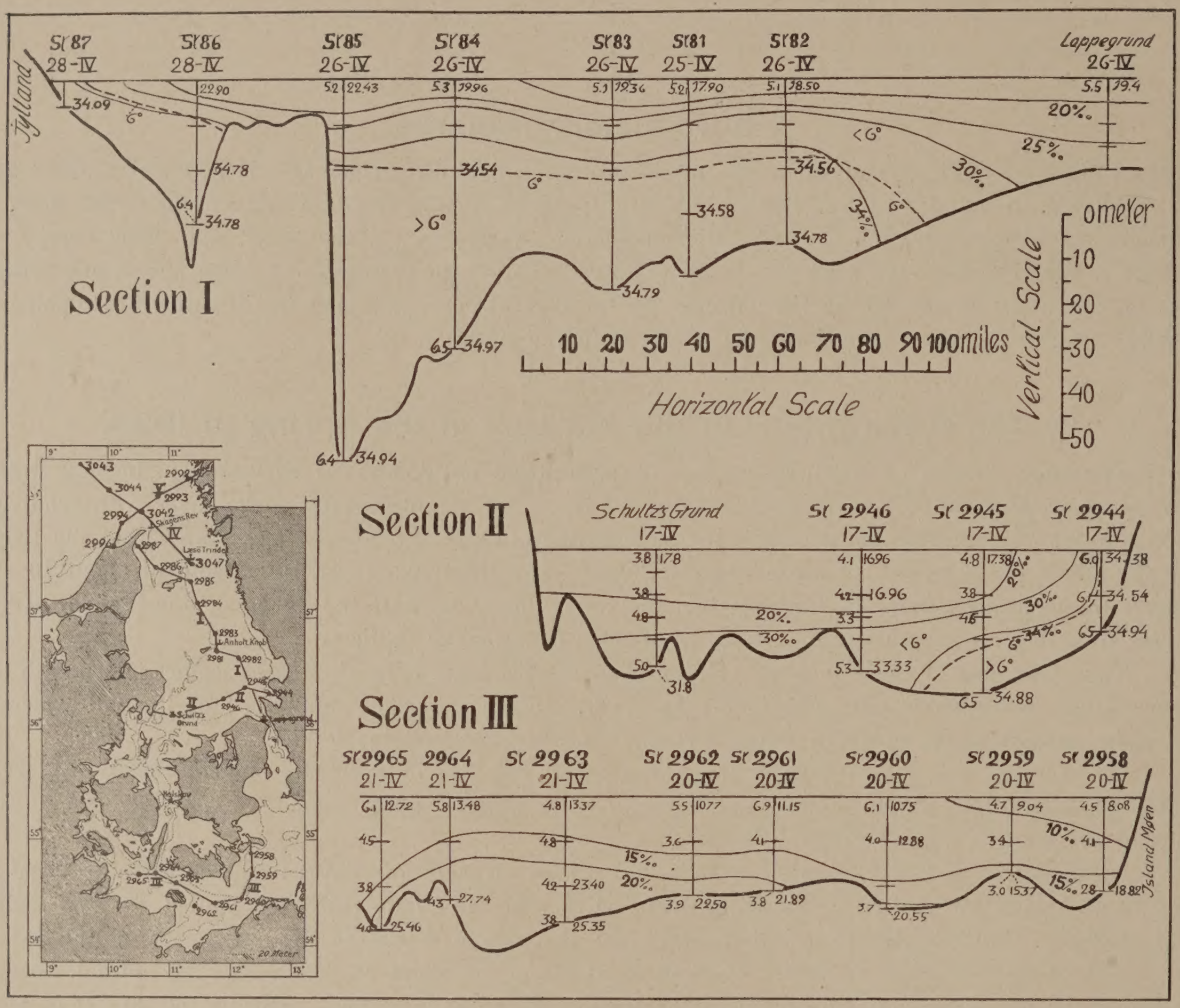

Fig. 1. Sections of the Kattegat and western Baltic from April of 1923.

The larvae of the HADDOCK (*Gadus æglefinus* L.) are normally wanting or very rare in the Kattegat, but in April and May of 1923 many larvae occurred there and some also in the Belt Sea, even so far south as the Kieler Bay.

The Green Cod (*Gadus virens* L.) is spawning in the northern part of the North Sea and the western Skagerak but not in the Kattegat or the Baltic. The inner limit of the distribution of larvae of this species is usually situated in the Skagerak, but larvae of this species were found, in April of 1923, both in the Kattegat and the northern part of the Sound.

The small pelagic young of the Sea-wolf (*Anarrhichas lupus* L.) of less than a year old, were found at several stations in the southern Kattegat, where they normally are very rare.

[1] One of these: *Diphyes arctica* Chun, was previously observed in the Skagerak and northern Kattegat.

The examples given here might be augmented by many others, but they are sufficient to show that numerous pelagic organisms were transported from the North Sea and Skagerak to the Kattegat and Belt Sea in the spring of 1923.

The inflow of North Sea water to the Kattegat and Belt Sea can be followed on various Danish light vessels, where daily observations are made of the temperature and salinity at various dephts.[1] We are thus able to determine when this great inflow of North Sea water began, and when it ceased. It appears from the Figures 3 and 4 that the period when the salinity was higher than normally, had the following duration:

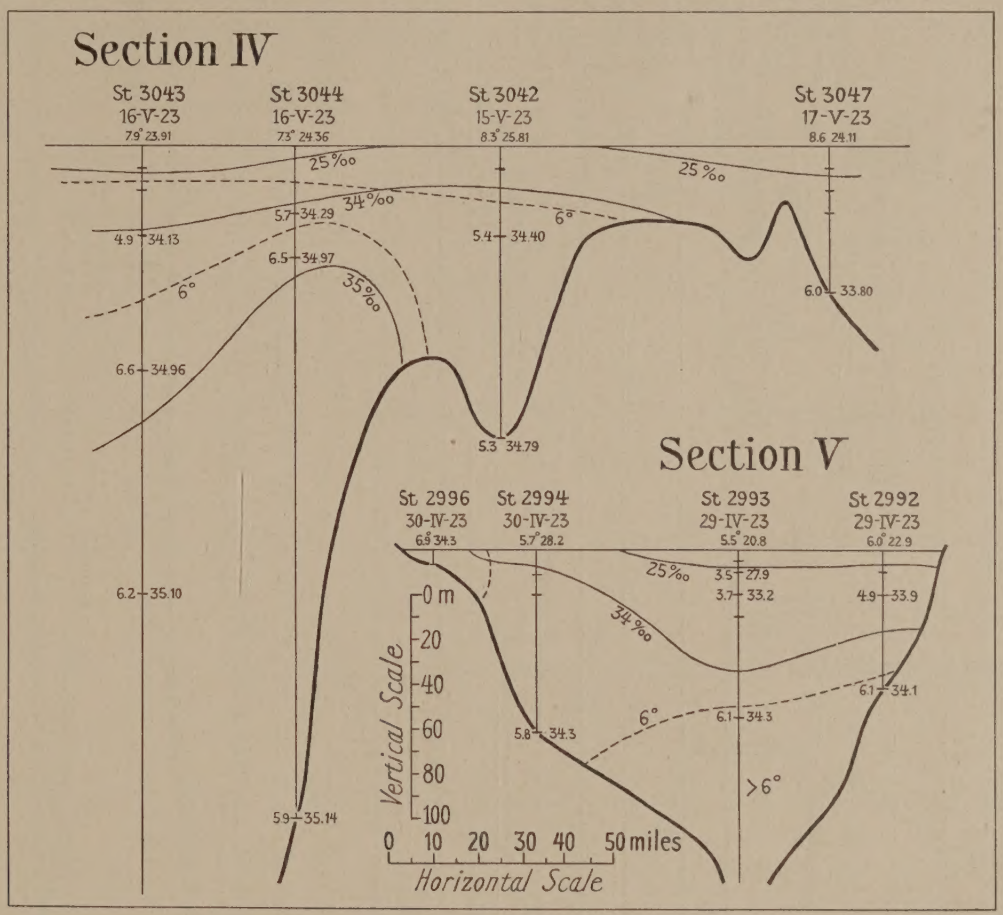

Fig. 2. Sections of the eastern Skagerak from April and May 1923, comp. Fig. 1.

At Skagen light vessel:	From beginning of February till 1st of May.
- Læsö Trindel light vessel:	middle of February till beginning of May.
- Anholt Knob — —	beginning of March till middle of May.
- Schultz' Grund — —	about 9. of March till 19. of June.
- Halskov Rev — —	— 13. of March till 29. of June.

It will be seen from Fig. 3 and 4 that the deviation from the mean values increases greatly from north to south in the Kattegat and Belt Sea.

The temperature of the water from the great inflow in April and May 1923 was about 1—2 degrees C. higher than normally.

[1] Nautisk Meteorologisk Aarbog, Kjøbenhavn.

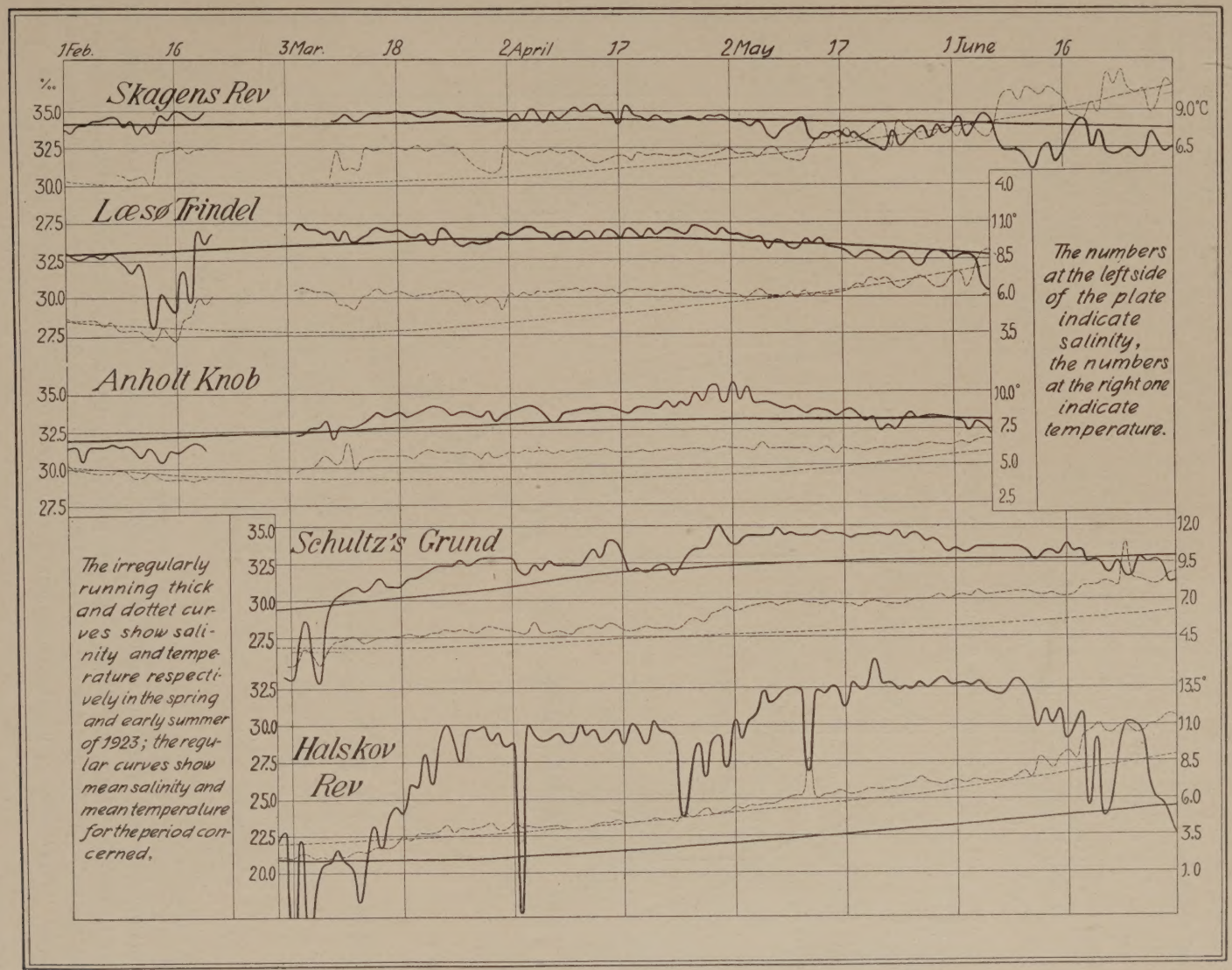

Fig. 3. Observations about Salinity and Temperature at the bottom at Danish light vessels in the spring and early summer of 1923.

Skagens Rev 38 m
Læsø Trindel 30 -
Anholt Knob 28 -
Schultz' Grund 26 m
Halskov Rev 20 -

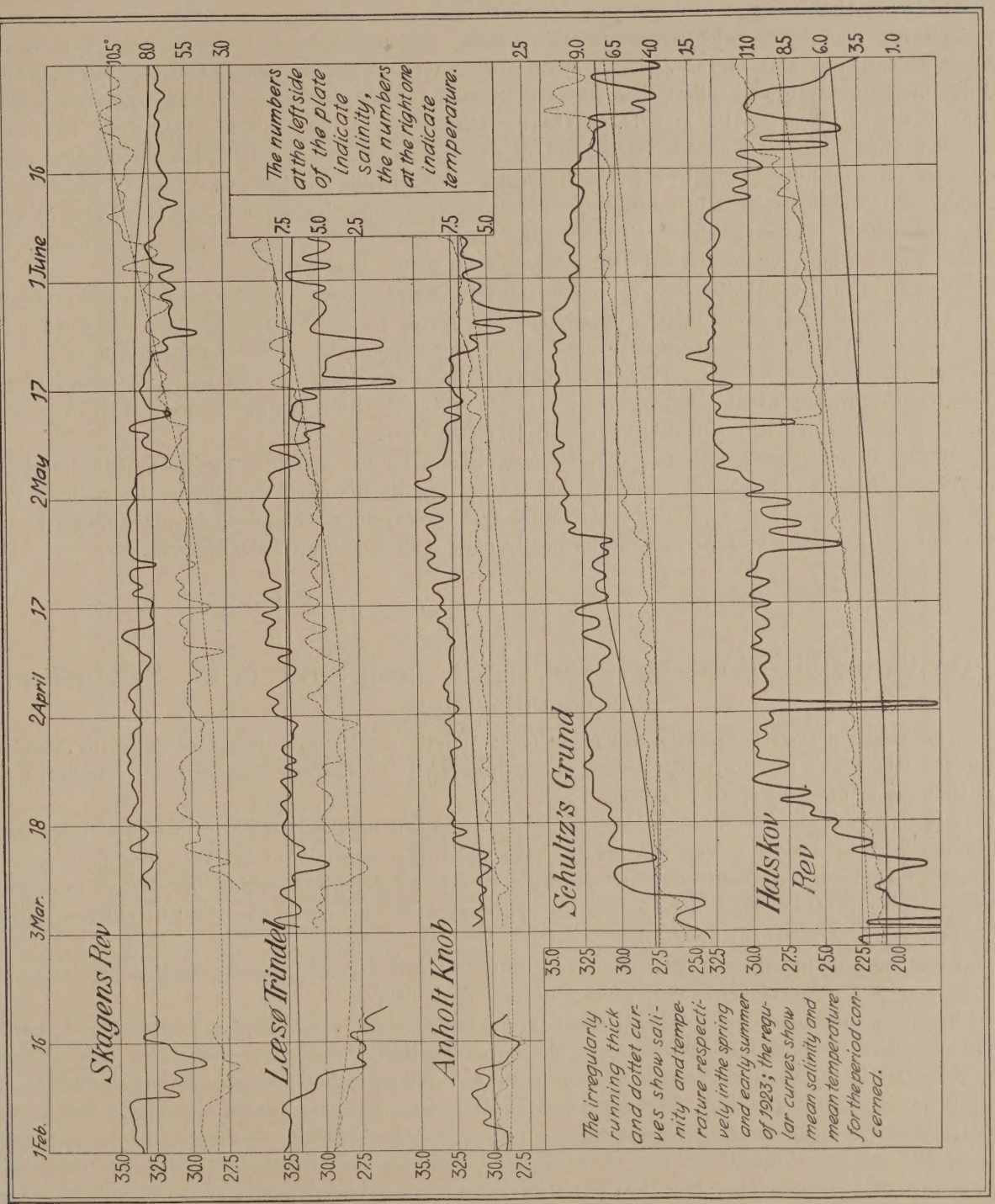
1 Feb.
16
3 Mar.
18
2 April
17
2 May
17
1 June
16
Skagens Rev
Læsø Trindel
Anholt Knob
Schultz's Grund
Halskov Rev
The numbers at the left side of the plate indicate salinity, the numbers at the right one indicate temperature.
The irregularly running thick and dotted curves show salinity and temperature respectively in the spring and early summer of 1923; the regular curves show mean salinity and mean temperature for the period concerned.

Fig. 4. Observations about Salinity and Temperature at 20 meters depth at Danish light vessels in the spring and early summer of 1923.

During the maximum inflow the upper layer of Baltic water was very thin in the Kattegat, and at certain places, e. g. in the Skälder Vik, where the mean salinity in the surface is about 15‰, North Sea water (of 34.38‰) was observed in the surface itself.

The water of between 34.50 and 35.00‰ salinity, which was found in the bottom layer of the Kattegat in April and May of 1923, was a mixture of North Sea water and Atlantic water. Water of the same temperature and salinity was observed at various stations in the eastern Skagerak in the middle of May at depths of ca. 50—100 m (Fig. 2). On the other hand, we see that the true North Sea water observed in the southern Skagerak at the end of April at ca. 20—80 m depth had a somewhat lower temperature and salinity. Normally it is North Sea water mixed with marginal coastal waters, which forms the water of the under current in the Kattegat during the spring months, but in the spring of 1923 Atlantic water, which had probably passed straight over the North Sea Plateau to the Skagerak, contributed considerably to the supply of the water in the under current of the Kattegat.

The great inflow of salt water in the spring of 1923 was preceded by a period when the salinity of the surface water was lower than normally, and this period persisted during the first stages of the inflow. Later on, in May, and especially in June, when the lower water layer of strong salinity became mixed up with the Baltic surface layer, the salinity of the surface water in the Kattegat became higher and the temperature lower than normally: The surface water of the Kattegat acquired in the early summer a more oceanic stamp than is usually the case.

During these circumstances my attention was caught by the fact that the yield of the mackerel fishery in the Kattegat in 1923 was much higher than is usually the case. The idea presented itself that there might be a connection between the extraordinary hydrographical conditions in the Kattegat in the spring and early summer of 1923 and the unusually high yield of the mackerel fisheries.

III. On the habits of the Mackerel and its occurrence in the Kattegat and adjacent waters.

The Mackerel (*Scomber scomber* L.) is a North Atlantic pelagic fish. It ranges from the Mediterranean to Iceland and the North of Norway, and it occurs also off the east coast of North America, from Cape Hatteras to the Gulf of St. Lawrence.

Different races of the mackerel occur, and it is apparent that the American mackerel differs from the European. It is not yet known whether we have more than one race in the West European waters. Here we are concerned specially with the North Sea mackerel, which during the winter, from December—January to April—May, lives to a great extent near the bottom of the Northern Plateau of the North Sea, where it is caught by trawl.

According to Ehrenbaum (1923) the food during this period consists mostly of Schizopods and Amphipods, and to a smaller degree of Copepods and young of fishes.

In the spring months, about April—May, the mackerel begin to rise from the bottom, and shortly after, a very large number leave the northern plateau of the North Sea. A few weeks later they occur in great quantities in the southern part of the North Sea and in the Skagerak and Kattegat, where the spawning takes place in June and July. The eggs, which are shed in the upper layers, are pelagic. Besides the spawning shoals a great number of young immature mackerel also leave the northern plateau and enter the southern part of the North Sea and the Skagerak and Kattegat in May and June. During this period the mackerel feeds mainly upon Plankton organisms, such as Crustaceans of the groups Schizopods, Amphipods, and Copepods, larvae of Decapods and Cirripedes, Clupeids, and Gadoids, etc. At this time of the year the mackerel are mostly caught by drift nets, and purse seines.

After spawning the mackerel spread over larger areas. In May and June comparatively few mackerel enter the Belt Sea, but during the course of the summer the stock is increased, and a small number immigrate even into the true Baltic. It seems that the mackerel in the period July—September is more predaceous than at other times of the year. Now very often they capture young of fishes: Clupeids, Gadoids, Ammodytes etc., and the fishing with trolling lines (dörg) begins. Often they come near to the coasts to feed upon shoals of young herrings and sprats, and here they are caught in great numbers in pound nets and land seines.

Fig. 5. The direction of the resulting Currents at ca. 30 meters depth in the North Sea and the Skagerak. Drawn up by Aage J. C. Jensen on the basis of publications of Wemyss Fulton, C. H. Brown, G. P. Bidder, G. Böhnecke, A. Schumacher, H. Keller, M. Knudsen, M. Knudsen and Kirstine Smith, J. Gehrke, O. Pettersson, Roosendaal and Wind, van Everdingen and Wind, etc.

In late autumn or beginning of winter when the cooling of the water sets in, the mackerel leave the Kattegat and Baltic waters and most of them the Skagerak also. There can be no doubt that at least a very great part of them spend the period January to April in the northern part of the North Sea, where the water at that time of the year is warmer than in the Kattegat, Belt Sea, and Baltic, and also warmer than in the greater part of the Skagerak. In the said period, great catches of Mackerel are taken at the bottom by trawl on the northern plateau of the North Sea.

The mackerel in the southern part of the North Sea disappear in late autumn and migrate partly northwards towards the northern plateau of the North Sea, and partly westward towards the Channel.

According to GARSTANG (1898) the mackerel of the Channel have the same racial characteristics as those of the North Sea.

The northern plateau of the North Sea, where the mackerel spend the winter months at the bottom, is covered by Atlantic water with a salinity of 35.00—35.25‰ and a temperature of 6—7° C. Water of the same salinity forms the bottom layer of the Skagerak, and some mackerel are taken there also with trawl during the winter. But the bottom water on the North Sea Plateau is a little warmer than that of the Skagerak, and it is clear from the catches that the North Sea Plateau is a much more favoured winter dwelling place for the mackerel than the bottom of the Skagerak.

When the mackerel rise from the bottom in the northern part of the North Sea in April and May, they gradually come up into water of between 34.00 and 35.00‰ salinity, and it is well known that this typical North Sea water circulates in such a manner, that a portion of it streams into the Skagerak and further into the Kattegat and Baltic waters, where it forms the under current and gradually becomes mixed with Baltic water (Fig. 5 and Fig. 6).

Table 1. Danish and Swedish catch of Mackerel in the Kattegat and Skagerak, in Tons.

	Danish catch[1]		Swedish catch[2]		Danish catch[1]		Swedish catch[2]
	Kattegat	Skagerak	Kattegat and Skagerak		Kattegat	Skagerak	Kattegat and Skagerak
1903....	85	8	1161	1914....	854	123	4564
1904....	107	4	1509	1915....	1291	321	4144
1905....	121	6	1441	1916....	1499	647	4866
1906....	417	40	1418	1917....	505	325	3883
1907....	372	6	1710	1918....	1431	948	7134
1908....	182	30	1799	1919....	684	688	6190
1909....	668	76	2303	1920....	1202	557	5759
1910....	287	78	1525	1921....	1464	220	4311
1911....	571	72	2737	1922....	1828	111	4611
1912....	695	64	3390	1923....	3628	107	5586
1913....	826	90	2372	1924....	2112[3]	306	

[1] After the official Danish Fiskeri-Beretning.
[2] After Bulletin Statistique and Sveriges officiella Statistik.
[3] The figures for 1924 are approximate. They are kindly supplied by Director F. V. MORTENSEN.

Table 2. Catch of Mackerel in the North Sea and the Kattegat and Skagerak, in Tons.

	Total catch in the North Sea[1]	Danish and Swedish catch in Kattegat and Skagerak[2]		Total catch in the North Sea[1]	Danish and Swedish catch in Kattegat and Skagerak[2]
1903.....	2265	1254	1914.....	15731	5541
1904.....	3355	1620	1915.....	9858	5756
1905.....	7360	1568	1916.....	11697	7012
1906.....	8099	1875	1917.....	6153	4713
1907.....	6958	2088	1918.....	3931	9513
1908.....	12305	1911	1919.....	9534	7562
1909.....	12314	3047	1920.....	12091	7518
1910.....	17383	1890	1921.....	10296	5995
1911.....	15108	3380	1922.....		6549
1912.....	17328	4149	1923.....		9321
1913.....	23819	3288			

[1] After Bulletin Statistique.
[2] After the official Danish Fiskeri-Beretning, Bulletin-Statistique, and Sveriges officiella Statistik.

Table 1 illustrates the yield of the Danish and the Swedish mackerel fishery in the Skagerak and Kattegat in each of the years 1903—1923(—24). As regards Sweden the statistics comprise both the Skagerak and the Kattegat, and the Swedish yield in each of these waters is not known. The monthly

Fig. 6. The direction of the resulting Currents in the intermediate layers (ca. 30—100 m) of the Skagerak and the lower layers of the Kattegat and Belt Sea. Drawn up by Aage J. C. Jensen on the basis of observations of O. Pettersson, G. Ekman, Martin Knudsen, J. P. Jacobsen, Ruppin etc.

catches are known only for a few years, but it appears that the main catch occurs in the Kattegat in June—July, and in the Belt Sea in July—September. The monthly distribution reckoned as percentage of the total Danish yield of the mackerel fisheries in the Kattegat was as follows:

	1886[1]	1910[2]	1911[2]
May	1	6	3
June	49	43	17
July	38	15	36
August	11	18	15
September	1	15	24
October		3	3
November			2

[1] After C. F. Drechsel (1890).
[2] After A. C. Johansen & E. Neergaard-Möller.

The Swedish and the Danish catch of mackerel in the Skagerak takes place mainly in the eastern part of this water, E. of 10° E. long. The main catch in the Kattegat takes place in the northern part of this water, N. of 57° N. lat.

IV. On a connection between the Salinity of the bottom water of the Kattegat in the month of May and the yield of the Mackerel Fishery.

If we consider the yearly yield of the mackerel fisheries in the Skagerak and Kattegat, we notice, as for most other fisheries, considerable fluctuations from year to year. In the period considered here:

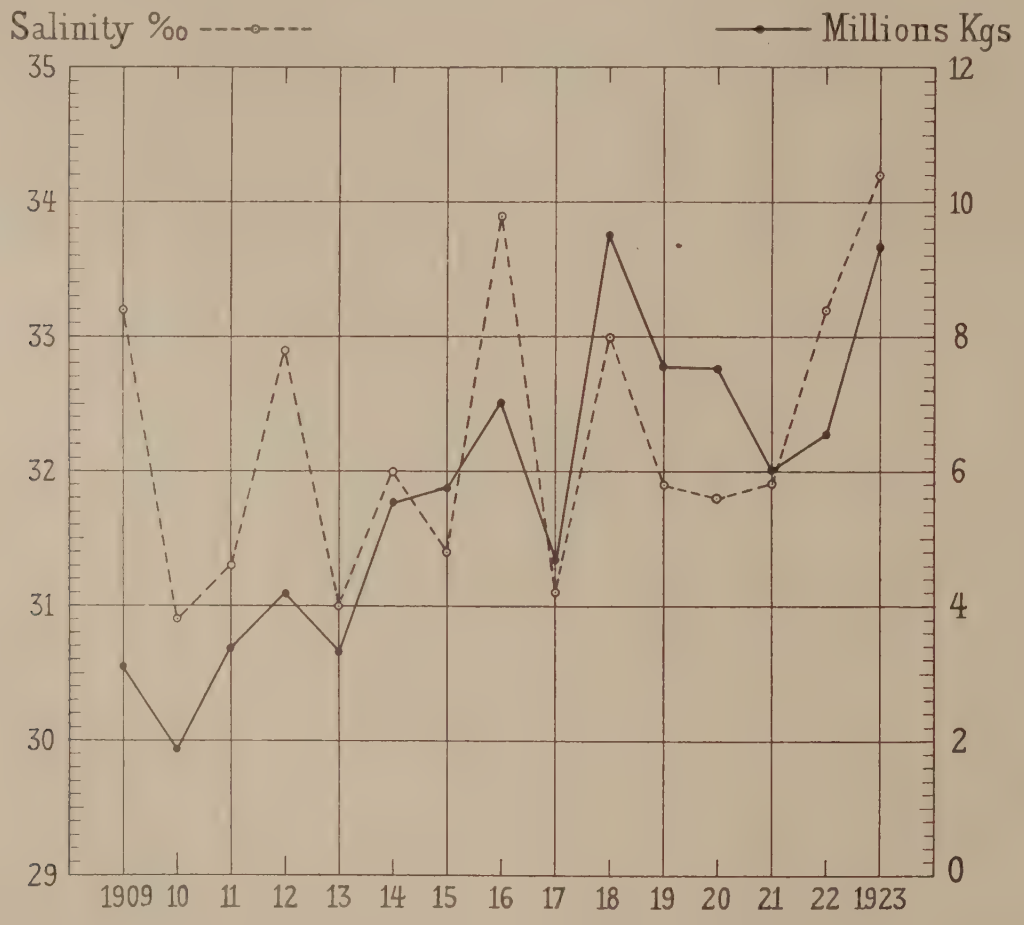

Fig. 7. The Danish and Swedish catch of Mackerel in the Kattegat and Skagerak and the mean salinity at Schultz' Grund light vessel at 26 m in the month of May.

from 1903 to 1924 there is a very strong increase in the yield, which is due to an increased fishery, but apart from that we see that some of the years, e. g. 1909, 1916, 1918 and 1923, are distinguished by an extraordinarily high yield, and other years as 1910, 1917 and 1921 by an extraordinarily low yield. We notice also that there is a certain agreement between the Swedish and the Danish catch (see Tab. 1), and

if we calculate the correlation coefficient for the years 1909—1923 between Swedish catch and Danish catch, we get:

$$r = 0.43 \quad \sigma_r = 0.21 \text{ and } \frac{r}{\sigma_r} = 2.0.^1$$

We will first investigate whether there is a connection between the yearly catch of the mackerel in the Kattegat and adjacent waters and the salinity of the bottom water of the Kattegat in the spring months.

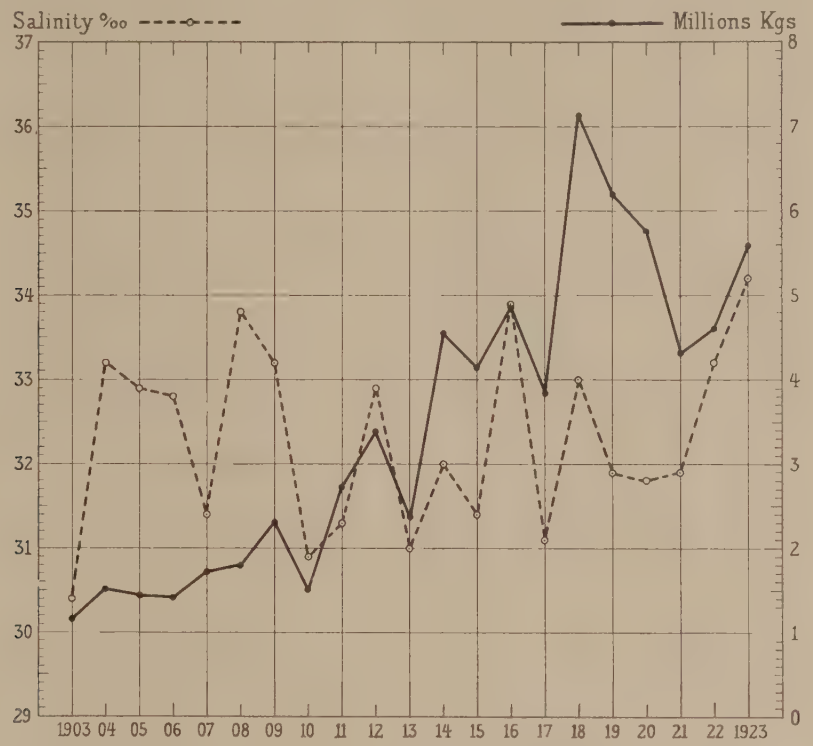

Fig. 8. The Swedish catch of Mackerel in the Kattegat and Skagerak 1903—23 and the salinity at Schultz' Grund light vessel at 26 m in the month of May.

If we study the Figures 7 and 8 showing the catch of mackerel in the Kattegat and Skagerak during a series of years and the mean salinity at Schultz' Grund light vessel at 26 m in the month of May, it appears that such a connection undoubtedly exists. There is a fair agreement between the curves showing the catch and those showing the salinity.

We have chosen the observations from the bottom layers at Schultz' Grund light vessel to represent the salinity of the bottom water of the Kattegat, as the deviations from the mean value are much greater at this place than at the more northern light vessels in the Kattegat and off Skagen (see Figs. 3—4). Casual disturbances here, caused by the wind etc. will not, therefore, exercise so much influence relatively as at the more northern light vessels in the Kattegat.

If we wish to calculate the correlation between the catch of mackerel and the salinity, we may take the deviation from the average catch for each year of the period concerned and correlate the anomalies with the salinity anomalies. As there is a strong increase in the catch during the period concerned owing to an

[1] Pearson's Formula: $r = \frac{\Sigma p a_x \cdot a_y}{\sqrt{\Sigma p' a_x^2 \cdot \Sigma p'' a_y^2}} = \frac{\Sigma p a_x \cdot a_y \quad n b_x \cdot b_y}{(n-1)\sigma_x \sigma_y}$ is used in this paper.

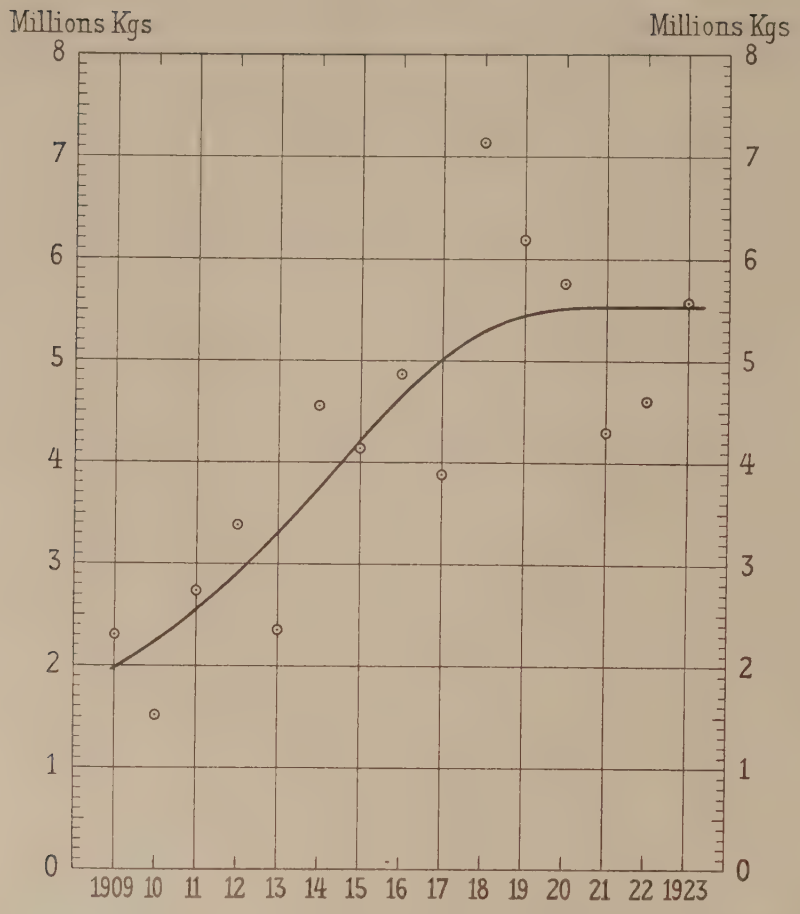

Fig. 9. The Swedish catch of Mackerel in the Kattegat and Skagerak 1909—23. The thick line represents the normal catch.

increased fishery, it is more rational to regard the deviations from the normal yield (See Table 3 and Figs. 9 and 10) and correlate the catch anomaly per cents[1] with the salinity anomalies. If we do so, we get the following results:

Correlation between catch anomalies per cents and salinity anomalies in the bottom water at Schultz' Grund light vessel at 26 meters depth in the month of May.

Swedish catch in Skagerak and Kattegat	1903—23	correlated with salinity at Schultz' Grund 26 m	$r = +0.43$; $\sigma_r = 0.18$
—	1909—23	—	$r = +0.45$; $\sigma_r = 0.21$
Danish catch in Skagerak and Kattegat	1903—24	—	$r = +0.41$; $\sigma_r = 0.18$
—	1909—24	—	$r = +0.68$; $\sigma_r = 0.13$
Danish and Swedish catch in Skagerak	1903—23	—	$r = +0.53$; $\sigma_r = 0.16$
Danish and Swedish catch in Kattegat	1909—23	—	$r = +0.66$; $\sigma_r = 0.15$
Danish catch in Kattegat	1903—24	—	$r = +0.34$; $\sigma_r = 0.19$
—	1912—24	—	$r = +0.57$; $\sigma_r = 0.18$
—	1915—24	—	$r = +0.73$; $\sigma_r = 0.15$

[1] By the catch anomaly per cent we understand the percentage which the difference between the observed yield and the normal yield makes of the normal yield (comp. J. P. Jacobsen & A. C. Johansen 1922).

We see here that a positive correlation is found in all cases, and that in most cases it is quite considerable. It is greater for the later part of the period 1903—24 than for the earlier part, and this is probably due to the fact that the yearly catch in the named period has increased strongly, so that it gives a much more trustworthy representation of the fluctuation in the stock for the later part of the period than for the earlier part. It should also be noted that a new mode of proceeding in the collection of the Danish fishery statistics began in 1909.

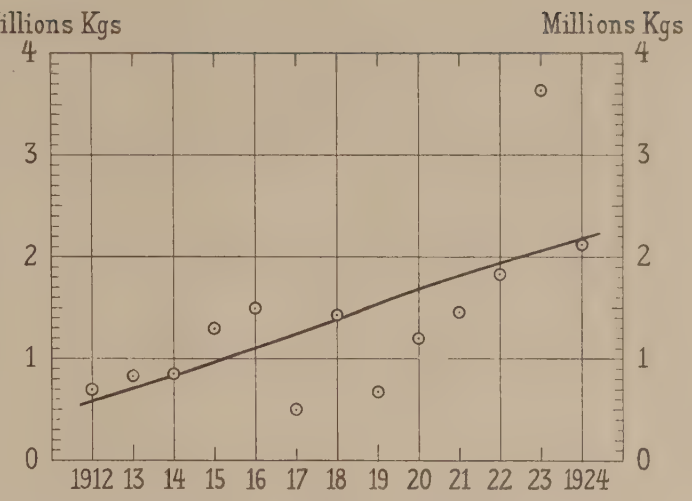

Fig. 10. The Danish catch of Mackerel in the Kattegat in 1912—24. The thick line represents the normal catch.

Between the temperature of the bottom water in the Kattegat in the spring months and the yearly catch of the mackerel, no correlation is found. If we calculate the correlation between the temperature at Schultz' Grund at 26 meters depth in May and the Swedish plus the Danish catch of mackerel for the period 1909—23, we get:

$$r = +0.09; \quad \sigma_r = 0.26.$$

This result is in agreement with the fact that the temperature is no good indicator for the strength of the inflow.

Table 3. Calculated normal catch of Mackerel in the Kattegat and Skagerak, in Tons. (Comp. Tables 1 and 2 and Figs. 9 and 10).

	Danish catch		Swedish catch	Danish and Swedish catch		Danish catch		Swedish catch	Danish and Swedish catch
	Kattegat	Kattegat and Skagerak	Kattegat and Skagerak	Kattegat and Skagerak		Kattegat	Kattegat and Skagerak	Kattegat and Skagerak	Kattegat and Skagerak
1903....	150	150	1230	1380	1914....	830	1100	3730	4830
1904....	180	175	1310	1480	1915....	970	1290	4220	5510
1905....	210	220	1390	1610	1916....	1100	1520	4640	6160
1906....	240	275	1500	1770	1917....	1240	1720	5010	6730
1907....	280	340	1610	1950	1918....	1390	1920	5280	7200
1908....	320	420	1760	2180	1919....	1540	2070	5430	7500
1909....	370	505	1980	2480	1920....	1680	2160	5510	7670
1910....	430	590	2240	2830	1921....	1820	2200	5530	7730
1911....	500	680	2550	3230	1922....	1950	2220	5530	7750
1912....	590	800	2900	3700	1923....	2070	2230	5530	7760
1913....	710	930	3300	4230	1924....	2180	2240		

The correlation between catch anomalies and salinity anomalies at Schultz' Grund 26 m is less for the month of April than for May, and less again for June than for April. As regards June the correlation found is so small that it is doubtful whether it is real:

Danish plus Swedish catch in Kattegat and Skagerak 1909—23 } correlated with salinity at Schultz' Grund 26 m {
April: $r = +0.42$; $\sigma_r = 0.21$
May: $r = +0.66$; $\sigma_r = 0.15$
June: $r = +0.14$; $\sigma_r = 0.25$

If we calculate the correlation between catch anomalies and salinity anomalies for the bottom water at the more northern light vessels of the Kattegat we get smaller values for the coefficient than for Schultz' Grund, as will be seen from the survey below:

Correlation between Danish plus Swedish catch of Mackerel in Kattegat and Skagerak in 1909—23 and:

1) Salinity Anholt Knob 28 m.....	March	$r = -0.03$	$\sigma_r = 0.26$
— — —	April	$r = +0.36$	$\sigma_r = 0.22$
— — —	May	$r = +0.15$	$\sigma_r = 0.25$
2) Salinity Læsø Trindel 20 m.....	March	$r = +0.06$	$\sigma_r = 0.26$
— — —	April	$r = +0.46$	$\sigma_r = 0.20$
— — —	May	$r = +0.07$	$\sigma_r = 0.26$
3) Salinity Skagens Rev 38 m.....	Feb.	$r = +0.19$	$\sigma_r = 0.27$
— — —	March	$r = +0.49$	$\sigma_r = 0.20$
— — —	April	$r = +0.06$	$\sigma_r = 0.26$
— — —	May	$r = +0.04$	$\sigma_r = 0.26$

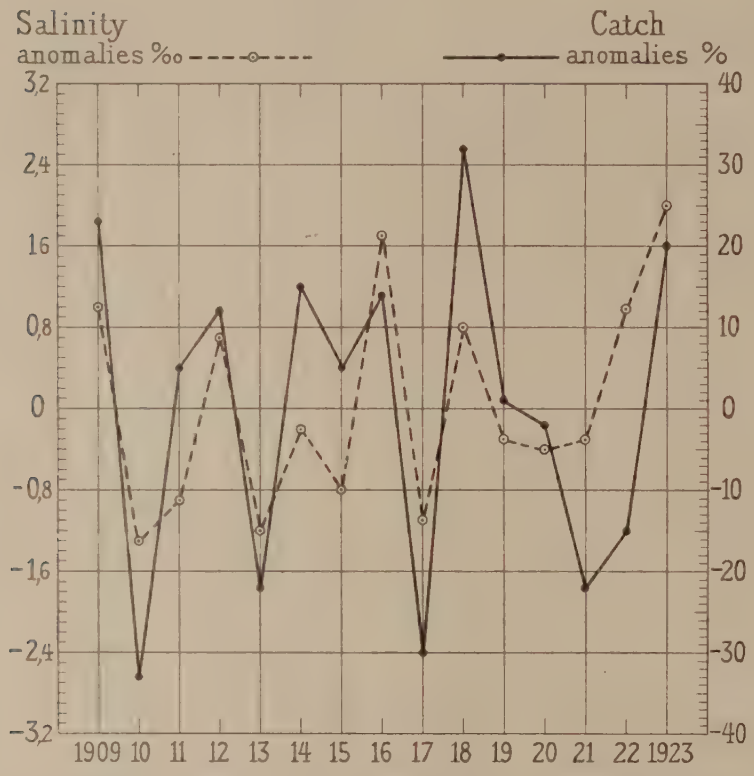

Fig. 11. Salinity anomalies, Schultz' Grund 26 m in May compared with catch anomalies in per cents from normal of the Danish and Swedish catch of Mackerel in the Kattegat and Skagerak in 1909—23.

Correlation between Danish plus Swedish catch of Mackerel in Kattegat and Skagerak 1903—23.

1) Salinity Anholt Knob 28 m.....	March	$r = -0.01$	$\sigma_r = 0.22$
— — —	April	$r = +0.27$	$\sigma_r = 0.20$
— — —	May	$r = +0.09$	$\sigma_r = 0.22$
2) Salinity Skagens Rev 38 m.....	Feb.	$r = +0.08$	$\sigma_r = 0.23$
— — —	March	$r = +0.38$	$\sigma_r = 0.19$
— — —	April	$r = +0.06$	$\sigma_r = 0.22$
— — —	May	$r = -0.03$	$\sigma_r = 0.22$

It will be seen that the correlation between the catch of mackerel and the salinity of the bottom water has the greatest value at Skagens Rev in March, at Læsø Trindel and Anholt Knob in April and at Schultz Grund in May. This harmonizes with the fact that the movement of the bottom waters from Skagens Rev to Anholt Knob takes about one month, and from Skagens Rev to Schultz' Grund about two months.[1]

V. Is the effect of the under current upon the yield of the Mackerel Fishery in the Kattegat of a direct or of an indirect nature?

The question now arises: how is the correlation observed between the salinity in the lower water layer and the catch of mackerel in the Kattegat to be explained? Do the results obtained denote that the mackerel follow the under current and appear at Skagens Rev in March, at Læsö Trindel and Anholt Knob in April and at Schultz' Grund in May? This explanation seems improbable. The mackerel has not hitherto been found in numbers in the northern Kattegat in March and April. The probability is then that the effect of the under current upon the mackerel is of an indirect nature, and we must therefore consider the fact that the water from the under current becomes mixed with the upper layer and in this way influences the temperature and salinity of the surface water.

If we calculate the correlation between the salinity at Schultz' Grund, 26 m, in May and the salinity at the surface at Schultz' Grund, Anholt Knob and Skagens Rev in May, June and July, we get the following result for the period 1909—23:

for May $r = +0.31$ $\sigma_r = 0.23$
- June $r = +0.70$ $\sigma_r = 0.13$
- July $r = +0.19$ $\sigma_r = 0.25$

A calculation between the salinity at Schultz' Grund at 26 m in May and the surface temperature in May, June and July for the same period and places gives:

for May $r = -0.38$ $\sigma_r = 0.22$
- June $r = -0.87$ $\sigma_r = 0.06$
- July $r = -0.38$ $\sigma_r = 0.22$

The results obtained show that a strong salinity in the bottom layer at Schultz' Grund in May is normally followed by an increase in the surface salinity and a decrease in the surface temperature in the same and the two ensuing months.[2] The effect observed is very great in the month of June.

It seems probable, therefore, that the mackerel is most frequent in the Kattegat in those years when the surface layer has a relatively high salinity and a relatively low temperature in the early summer. In order to throw light upon this question we shall investigate how great the correlation is between the salinity of the surface water in the Kattegat in May and June and the catch of mackerel in a fishing season, and between the temperature and the catch of mackerel.

A. The Correlation between the salinity anomalies of the surface water at Skagens Rev, Anholt Knob and Schultz' Grund and the catch anomalies per cents:

Salinity at Skagens Rev, Anholt Knob, Schultz' Grund, surface. May	correlated with Swedish catch in the Kattegat and Skagerak 1903—23	$r = +0.15$	$\sigma_r = 0.21$.
do.	correlated with Danish and Swedish catch in the Kattegat and Skagerak 1903—23	$r = +0.11$	$\sigma_r = 0.22$.

[1] Correlation between the salinity at Schultz' Grund 26 m May and
a) Salinity Anholt Knob 28 m 1903—23, April: $r = +0.71$ $\sigma_r = 0.11$,
b) — Læsø Trindel 20 m 1909—23, April: $r = +0.56$ $\sigma_r = 0.18$,
c) — Skagens Rev 38 m 1903—23, March: $r = +0.55$ $\sigma_r = 0.15$.

[2] In this way the under current in May has some influence upon the climate of Denmark and South Sweden in early Summer.

Salinity at Skagens Rev, Anholt Knob, Schultz' Grund, surface. May	correlated with Danish and Swedish catch in the Kattegat and Skagerak 1909—23	$r = +0.13$	$\sigma_r = 0.25$
do.	correlated with Danish catch in the Kattegat and Skagerak 1903—24	$r = -0.10$	$\sigma_r = 0.21$
do.	correlated with Danish catch in the Kattegat and Skagerak 1909—24	$r = +0.24$	$\sigma_r = 0.24$
Salinity at Skagens Rev, Anholt Knob, Schultz' Grund, surface. June	correlated with Swedish catch of mackerel in the Kattegat and Skagerak 1903—23	$r = +0.24$	$\sigma_r = 0.21$
do.	correlated with Danish and Swedish catch in Skagerak and Kattegat 1909—23	$r = +0.47$	$\sigma_r = 0.20$
do.	correlated with Danish catch in the Kattegat and Skagerak 1903—24	$r = +0.36$	$\sigma_r = 0.19$
do.	correlated with Danish catch in the Kattegat and Skagerak 1909—24	$r = +0.57$	$\sigma_r = 0.17$

B. The Correlation between the temperature anomalies of the surface water at Skagens Rev, Anholt Knob and Schultz' Grund and the catch anomalies per cents:

Temperature at Skagens Rev, Anholt Knob, Schultz' Grund, surface May.	correlated with Swedish catch of mackerel in the Kattegat and Skagerak 1903—23	$r = -0.11$	$\sigma_r = 0.22$
do.	correlated with Danish and Swedish catch in the Kattegat and Skagerak 1903—23	$r = -0.12$	$\sigma_r = 0.22$
do.	correlated with Danish and Swedish catch in the Kattegat and Skagerak 1909—23	$r = -0.17$	$\sigma_r = 0.25$
do.	correlated with Danish catch in the Kattegat and Skagerak 1903—24	$r = -0.06$	$\sigma_r = 0.21$
do.	correlated with Danish catch in the Kattegat and Skagerak 1909—24	$r = -0.38$	$\sigma_r = 0.21$
Temperature at Skagens Rev, Anholt Knob, Schultz' Grund, surface. June	correlated with Swedish catch of mackerel in the Kattegat and Skagerak 1903—23	$r = -0.35$	$\sigma_r = 0.19$
do.	correlated with Danish and Swedish catch in Skagerak and Kattegat 1903—23	$r = -0.58$	$\sigma_r = 0.14$
do.	correlated with Danish and Swedish catch in Skagerak and Kattegat 1909—23	$r = -0.67$	$\sigma_r = 0.14$
do.	correlated with Danish catch in the Kattegat and Skagerak 1903—24	$r = -0.56$	$\sigma_r = 0.15$
do.	correlated with Danish catch in the Kattegat and Skagerak 1909—24	$r = -0.84$	$\sigma_r = 0.07$

The results obtained suggest that the temperature of the upper water layer in the month of June exercises a predominant influence upon the frequency of the mackerel in the Kattegat and eastern Skagerak (comp. Fig. 12). The salinity of the surface waters has probably also some influence upon the occurrence of the mackerel in these waters.

The observations available are then in favour of the following view: The mackerel migrate to the Kattegat and Skagerak in the surface waters, and are not substantially transported to these waters by the under current in the spring months. The immigration in the upper layer begins in May and reaches its maximum already in June. This interpretation is in agreement with the observations to hand: The mackerel in the Kattegat is caught almost exclusively in the upper layer. The fishing begins in May but is not of great importance until June. It reaches usually its maximum in June or July.

It seems natural that the mackerel should prefer a relatively high salinity in the Kattegat when spawning there in June or July. David Nilsson (1914), who studied the spawning conditions in the Skage-

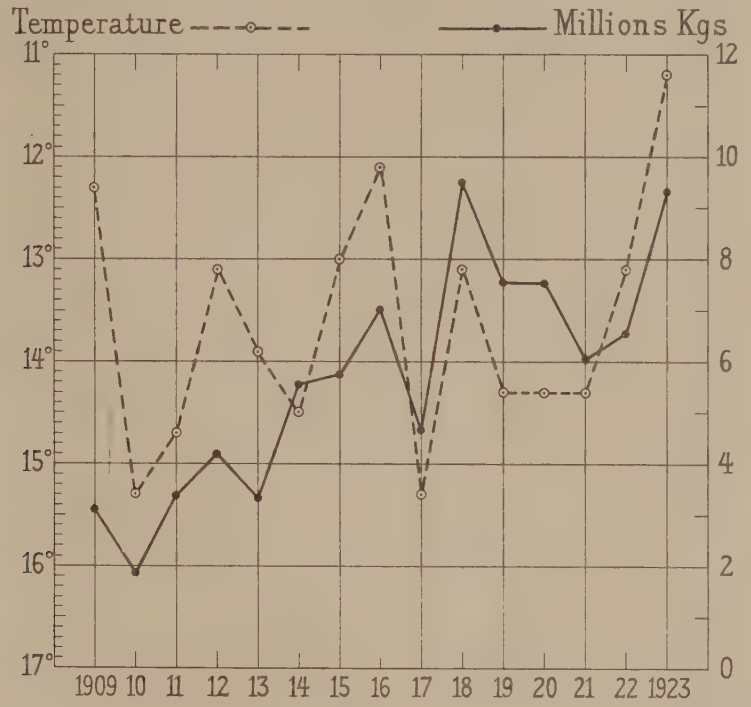

Fig. 12. Temperature in the surface water in June at Skagens Rev, Anholt Knob and Schultz' Grund, compared with Danish and Swedish catch of Mackerel in the Kattegat and Skagerak in the years 1909—23.

rak and Kattegat, states that in waters of less than 26 ‰ salinity only a relatively small number of mackerel eggs are found, and where the salinity was considerable below this value, they were generally shrunken and spoiled, presumably owing to osmotic pressure. He observed that the eggs of the mackerel were far less numerous in the upper layer of the eastern Skagerak and the Kattegat, where the Baltic surface water predominates, than in the salter strata beneath.

According to Nilsson the lower vertical limit of general distribution for the eggs of the mackerel coincides approximately with the 32—33 ‰ water in the eastern Kattegat.

Most of the eggs of the mackerel in the North Sea and the Skagerak develop at a temperature between 11° and 15° C. According to Ehrenbaum (1923) the planktonic eggs of the mackerel are more frequent off the south and south west coast of Norway than anywhere else in the North Sea. They occur there mostly in the surface layer, and the mean temperature there is 11° to 12° C. in June and 13° to 15° C. in July.

From Tables 4 and 5 it appears that the temperature in a certain part of the period June—July every year is between 11° and 15° C. in the water layers of 26—33 ‰ salinity in the eastern Kattegat, where the eggs of the mackerel mainly occur.

Table 4. Observations of temperature in surface waters and at the levels of 26‰ and 33‰ salinity at Læsö Trindel light vessel.

	June Temperature			July Temperature		
Year[1]	0 m	at 26‰	at 33‰ or bottom[2]	0 m	at 26‰	at 33‰ or bottom[2]
1909	12.7	11.9	bottom 20 m 9.2	15.2	15.1	bottom 20 m 13.2
1910	15.6	12.0	— — 10.3	17.3	16.2	— — 14.5
1911	15.0	12.3	— — 9.9	15.9	15.8	— — 14.1
1912	13.3	12.8	— — 10.5	18.1	14.6	— — 12.5
1913	14.1	12.9	— — 10.7	17.0	16.2	— — 13.4
1914	14.5	11.7	— — 9.2	19.1	17.3	— — 15.1
1915	12.6	12.4	— — 9.8	15.0	14.8	— — 13.0
1916	12.1	11.0	— — 9.6	16.5	14.7	— — 13.0
1917	15.4	12.6	— — 10.4	17.3	16.1	— — 13.0
1918	13.1	13.1[3]	— — 11.1	15.9	14.9	— — 13.0
1919	13.9	13.9[3]	— — 11.5	16.5	15.8	— — 14.0
1920	14.6	13.5	— — 10.7	16.5	16.2	— — 15.2
1921	14.4	13.7	bottom 30 m 11.0	15.6	15.6	at 33‰ 12.1
1922	12.9	12.7	— — 9.1	15.0	14.6	— 13.1
1923	11.2	11.2[3]	— — 9.2	15.9	15.1	bottom 30 m 11.6

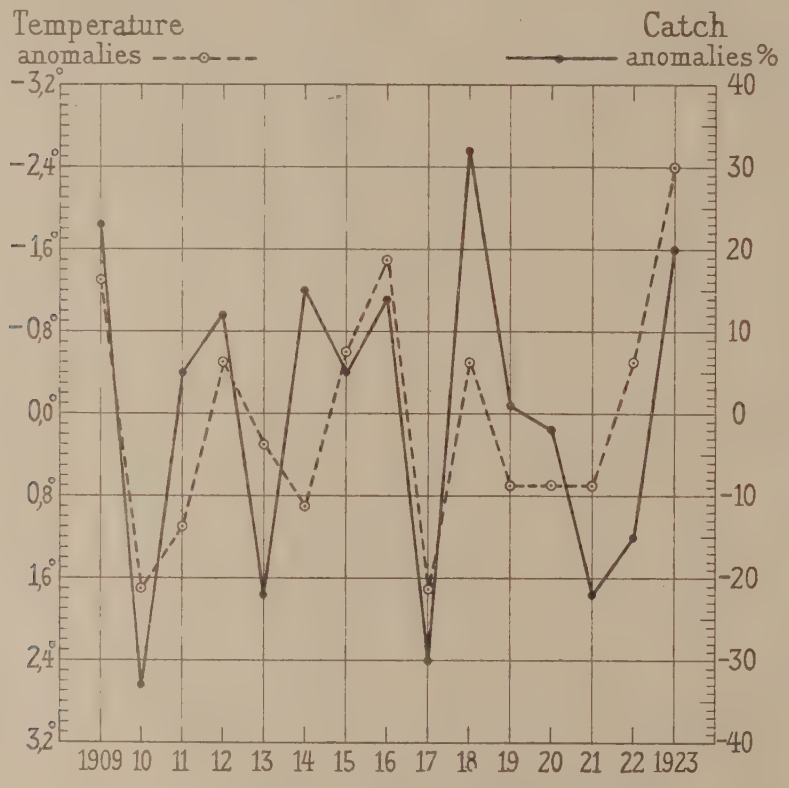

Fig. 13. Temperature anomalies for surface water in June at Skagens Rev, Anholt Knob and Schultz' Grund compared with catch anomalies in per cents of normal of the Danish and Swedish catch of Mackerel in the Kattegat and Skagerak in 1909—23.

The mackerel will always find in June or July a suitable temperature for the development of the eggs in the water layers of between 26 and 33‰ salinity in the eastern Kattegat, but if they migrate

[1] The rich mackerel years are given in heavy figures.

[2] The temperature is given for the bottom, when 33‰ is not reached at bottom.

[3] The salinity at the surface was more than 26‰, and the temperature at the surface is stated.

Table 5. Observations of temperature in surface waters and at levels of 26‰ and 33‰ salinity at Anholt Knob light vessel.

	June Temperature			July Temperature		
Year[1]	0 m	at 26‰	at 33‰ or bottom[2]	0 m	at 26‰	at 33‰ or bottom[2]
1909	12.7	11.0	at 33‰ 6.4	15.5	14.2	at bottom 10.7
1910	15.6	11.0	— 6.9	17.3	14.9	— 10.2
1911	15.1	10.0	— 7.7	16.0	14.4	— 10.4
1912	13.4	10.4	at bottom 7.6	18.3	13.6	— 10.3
1913	14.2	11.2	— 7.7	17.0	13.8	— 9.0
1914	15.1	11.0	— 5.8	19.5	15.6	— 9.6
1915	13.2	10.0	— 5.5	15.8	13.5	— 9.7
1916	12.6	9.4	— 6.5	16.7	13.1	— 9.5
1917	15.8	9.4	— 5.8	17.7	14.5	— 8.5
1918	13.3	13.0	— 7.4	15.9	15.6	— 10.5
1919	14.8	14.0	at 33‰ 8.3	16.7	15.6	— 10.8
1920	14.7	10.4	at bottom 6.9	17.0	14.7	— 10.6
1921	14.5	12.7	at 33‰ 8.9	16.4	15.6	— 10.3
1922	13.5	11.2	at bottom 6.9	15.3	12.9	— 11.1
1923	11.7	11.1	— 7.9	15.8	13.9	— 10.4

towards the Kattegat in the surface layers, a relatively high temperature may prevent many of them from immigration. It appears from Tables 4 and 5 that the temperature in the surface in the eastern Kattegat is usually much more than 15° C. in July and sometimes over that value in June also. From the survey below it will be seen that the mean temperature for the surface water in the eastern Kattegat in the month of July is high in comparison with most other areas where the mackerel is spawning.

Mean temperature in the surface waters at different spawning places for the Mackerel.

Area	Spawning period	Temperature °C.
Western part of Mediterranean	March	14—15
— —	April	16
Atlantic S. of Ireland	May	11—12
— —	June	13—14
— —	(July)	15—16
Western part of Channel	May	11—12
— —	June	13—14
— —	July	15—16
West of Scotland	June	11
— —	July	13
Southern part of North Sea	June	13—14
— —	July	15—17
Middle part of North Sea. Off shore waters	June	11—12
—	July	13—15
Northern Plateau of North Sea	June	10—11
—	July	12—14
North Sea off Norway	June	11—12
	July	13—14
Eastern Skagerak	June	13
— —	July	15—16
Eastern Kattegat	June	14—15
— —	July	16—17

[1] The rich mackerel years are given in heavy figures.

[2] The temperature is given for the bottom, when 33‰ is not reached at bottom (28 m).

As mentioned above (p. 8) the great inflow of North Sea water in April and May of 1923 was preceded by a period during which the salinity in the surface water was lower than normally, and suc-

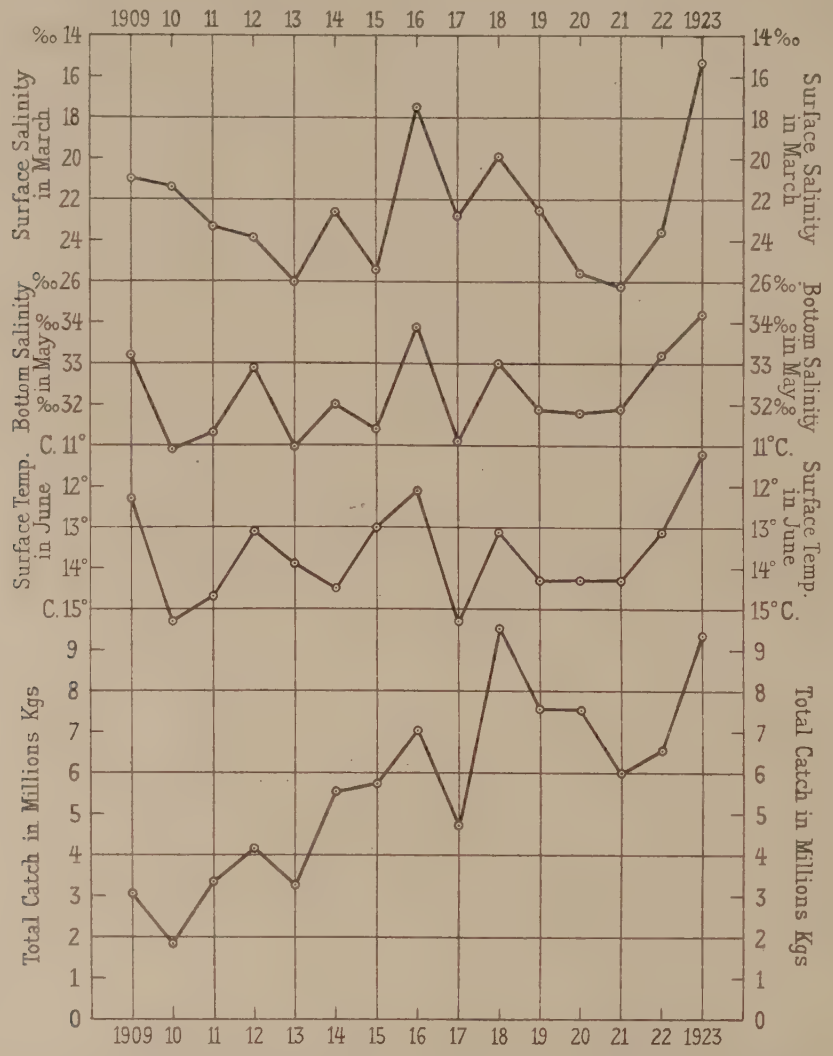
1909 10 11 12 13 14 15 16 17 18 19 20 21 22 1923
Surface Salinity in March
Bottom Salinity in May
Surface Temp. in June
Total Catch in Millions Kgs

Fig. 14. Comparison between surface salinity in March, bottom salinity in May, surface temperature in June, and Danish and Swedish catch of Mackerel in the Kattegat and Skagerak 1909—23. (Surface salinity and surface temperature are means of observations at Skagens Rev, Anholt Knob and Schultz' Grund. Bottom salinity is taken from Schultz' Grund at 26 m).

ceeded by a period in which the surface water was more saline, but colder than normally. It will now be worth while to calculate the correlation between the salinity of the bottom water in May and the salinity of the surface water in the period prior to May.

If we calculate the correlation between the salinity at 26 m at Schultz' Grund in May and the salinity at the surface at Schultz' Grund, Anholt Knob, and Skagens Rev in the preceding months, we get the following results for the period 1909—23:

February: ..... $r = -0.15$ $\sigma_r = 0.25$
March: ..... $r = -0.70$ $\sigma_r = 0.13$
April: ..... $r = -0.49$ $\sigma_r = 0.20$

The results obtained show that a high salinity in the under current in May is normally preceded by a low salinity in the surface water in March and April. This fact in connection with the results arrived at above (p. 12—16) indicates that there must be some correlation between the salinity of the surface water in March—April and the catch of mackerel in the following fishing season. If we calculate the correlation between the salinity of the surface water in March and April at Skagens Rev, Anholt Knob and Schultz' Grund and the catch of mackerel from Denmark and Sweden in the period 1909—23, we get the following result:

March: ..... $r = -0.51$ $\sigma_r = 0.19$
April: ..... $r = -0.39$ $\sigma_r = 0.22$
March plus April: ..... $r = -0.53$ $\sigma_r = 0.19$

We see here that when the salinity in the upper water layer is lower than usually in March and April, the yield of the mackerel fisheries in the succeeding fishing season (in June—October) will probably be above the normal.

It would be of interest to know whether there is any connection between the amount of Plankton in spring and early summer and the yearly catch of mackerel in the Kattegat. Professor C. H. Ostenfeld has kindly placed at my disposal the results of some plankton collections made by vertical hauls at Anholt Knob. The hauls were taken with a Nansen Net of Müller gaze with 23 strands in 10 mm. The opening of the net was 50 cm in diameter (area 1963 cm). The plankton was preserved in 3—4 % formalin and the volumes given below are those read off in measuring glasses in which the plankton samples were placed for 48 hours for precipitation.

Plankton volumes in ccms. of samples taken with Nansen Net at Anholt Knob light vessel 28—0 m (measured by P. Jespersen).

	1/4	15/4	1/5	15/5	1/6	15/6	Average, April—May	Average, June
1910	12.0	2.5	5.0	3.5	2.5	6.0	5.75	4.25
1911	18.0	8.5	5.0	10.5	3.5	7.5	10.5	5.5
1912	2.0	22.0	3.0	12.5	2.5	0.5	9.87	1.5
1913	3.5	3.0	3.5	3.0	1.5	2.0	3.25	1.75
1914	3.5	4.5	4.0	1.5	0.5	0.5	3.37	0.5

The main part of the plankton taken in the period 1. April to 15. May was plant plankton, and the main part taken in June was animal plankton, chiefly Copepods. — It will be seen that in 1912 and 1914 the volume of animal plankton was smallest.

The result obtained points in the direction that the amount of animal plankton in the Kattegat in early summer should be smallest in those years when most mackerel occur there, but the figures showing the volumes of plankton are very variable, and it is quite clear that the material to hand does not afford a reliable basis for any conclusion to that effect. There is probably a correlation between the amount of plant plankton in the spring months and of animal plankton in early summer, but the figures obtained throw very little light upon this.

We have shown that the mackerel catch in the Kattegat is greatest in the years when the surface temperature in the month of June is lower than normally, but we do not know the connection between temperature and the amount of Plankton. Allen (1909) and Lumby (1923) have investigated whether there is a connection between the surface temperature in the Channel in the spring months and the catch of mackerel, and both of them are of opinion that it is very doubtful whether such a connection exists. On the

other hand, ALLEN has demonstrated that there is probably a connection between number of hours of bright sunshine recorded for the months February and March at Plymouth, Falmouth etc. and the average number of Mackerel landed per boat in the month of May during the period 1902—08.

It might be suggested that the fluctuations observed in the yield of the Danish and Swedish mackerel fisheries in the Kattegat and Skagerak, were due to good and bad survival years for the young ones, as

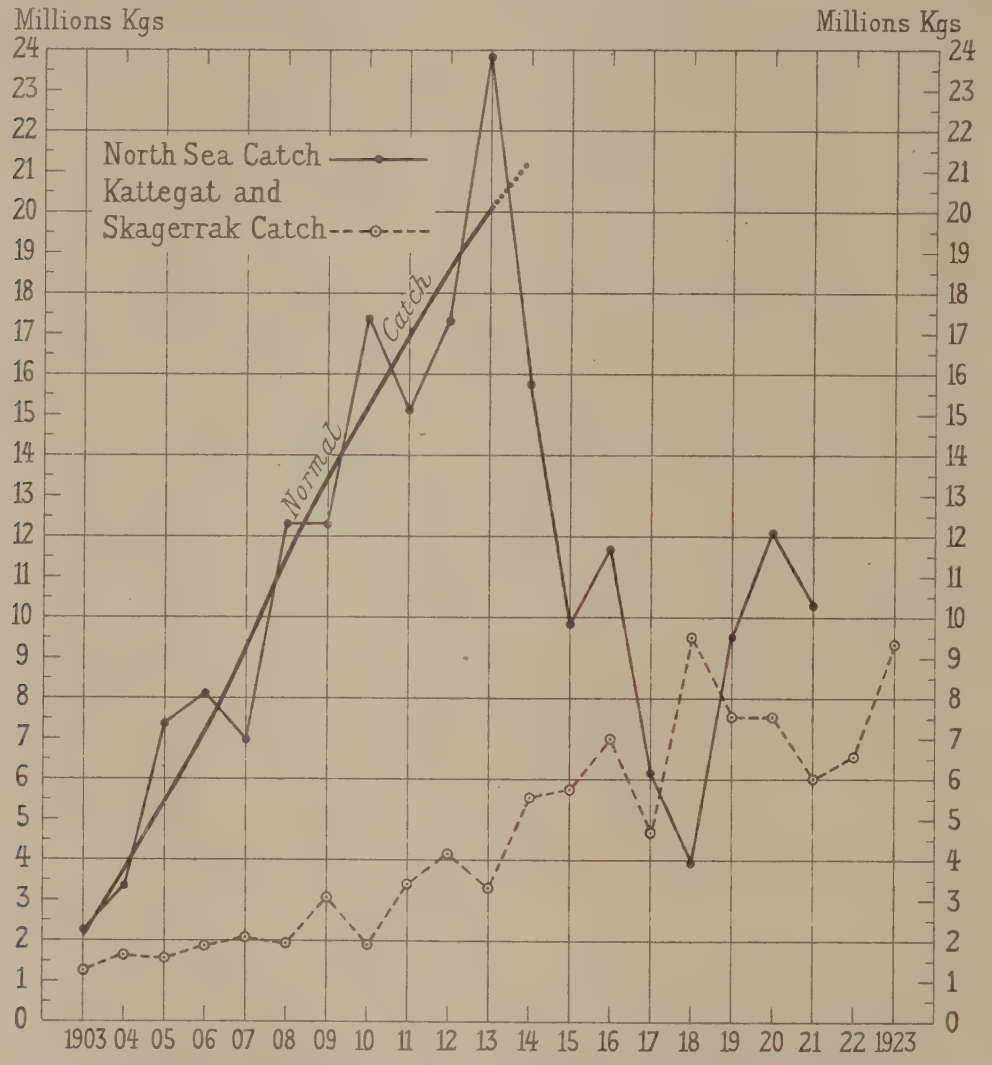

Fig. 15. Comparison between the total catch of Mackerel in the North Sea and the Danish and Swedish catch in the Kattegat and Skagerak in the years 1903—23.

in the case of several other fish, e. g. Herring, Plaice, Cod and Haddock etc. In this case we should expect to find a positive correlation between the yield in the Kattegat—Skagerak and the yield in the North Sea. From Fig. 15 we see, however, that such a correlation does not exist; indeed we find, on the contrary, a negative correlation. In the years when the catch is relatively high in the Skagerak and Kattegat, it is relatively low in the North Sea. This fact confirms the view that the mackerel occurring in the Skagerak and Kattegat belong to the stock of the North Sea.

If we calculate the correlation between the anomalies of the total catch of mackerel in the North

Sea in 1903—1914 and those of the Danish and Swedish catch of mackerel in Skagerak and Kattegat we get:

$$r = -0.62, \quad \sigma_r = 0.18.$$

It will be seen from Fig. 15 that the yield of the mackerel fisheries in the North Sea decreased extremely during the Great War. In the period 1913—1918 it went down from about 24 to about 4 millions Kilograms, and in 1918 it was even lower than the yield in the Kattegat—Skagerak.

VI. On the practical importance of these investigations.

It appears from the preceding pages that there is a connection between the following phenomena in the Kattegat:

1) A strong ingoing current in the lower water layer in April—May, indicated by a high salinity in this layer.
2) A low temperature of the surface waters in June.
3) A great amount of mackerel in the Kattegat, as shown by a large yearly catch.

It has been shown that a period with relatively high salinity of the bottom layer in April—May is normally preceded by a period with relatively low salinity in the surface layer in March—April. We shall be able to predict, therefore, with a certain degree of probability, whether it will be a good or bad mackerel year as soon as the observations of the salinity in March and April are to hand, or about 1 to 2 months before the fishery in the Kattegat begins. When the observations of the salinity of the lower layer for the months of April and May are available we can predict the yield with greater probability.[1] Such a prediction is of importance both for the fishermen who make preparations for the fishing, and for the fishmongers and the people connected with the fishing industry, who make arrangements for the salting, canning, kippering or freezing of the fish.

In the prediction about the yield it is assumed that no very great alteration in the manner of fishing or intensity of fishing takes place during the season in question.

I wish to thank Hr. cand. mag. Aage J. C. Jensen for his valuable assistance with the statistical and hydrographical work.

[1] The predictions will be published in "Dansk Fiskeritidende".

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